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REVIEW OF THE GEOLOGICAL LITERATURE OF THE SOUTH AFRICAN REPUBLIC.[1]

Topography.—The most characteristic features of South African topography appear to be its table lands. The interior of the country is in great measure a vast extent of high plateaux—the Hooge Veldt—which, though grassy, are practically treeless and present much the same aridity and desolateness of aspect as many of our western mesas. Along the coast, especially on the south and east, is a belt of country of a generally lower level, which is more rugged and broken, but even here plateaux occur, sometimes on the very coast, as, for instance, the well-known Table Mountain near Capetown.

As one leaves the coast to go into the interior the country becomes more mountainous, often rising into considerable ranges like the Drakensberg range, which runs parallel to the southeast coast and has peaks rising to elevations of 10,000 feet or more.[2]

[1] Read before the Geological Society of Washington, November 13, 1895.

[2] AUTHORITIES CONSULTED IN THE PREPARATION OF THE PRESENT PAPER.

1888. A. H. GREEN: Geology and Physical Geography of the Cape Colony, Quar. Jour., Vol. 44, pp. 239–270.

1889. A. SCHENCK: Vorkommen des Goldes in Transvaal. Zeitsch. d. Deut. Geol. Gesellsch, Band XLI., pp. 573–581.

1890. W. H. FURLONGE: Geology of the De Kaap Gold Fields. Trans. Amer. Inst. Mg. Engrs, Vol. XVIII., pp. 334–348.

1891. W. H. PENNING: A Contribution to the Geology of the Southern Transvaal. Quar. Jour., Vol. XLVII., pp. 451–463.

As a rule, however, these mountains do not reach above the level of the high plateau, which forms an abrupt escarpment near or behind them, and slopes away gently toward the interior. Thus the drainage of the plateau region from within 100 miles or less of the east coast flows westward through the various tributaries of the Orange River into the Atlantic Ocean. The country is yet too new and too little explored by geologists to afford certain data for a physical description founded on its previous geological history, such as would be given by a physical geographer of the present school like our William M. Davis, but it is evident that the region presents a most interesting and fruitful field for this line of study. From what has already been written it is easy to make the preliminary deduction that the coast belt, like the east coast of Lower California, shows an older topography that has been exposed by the denudation of the more recent formations that constitute the plateau regions.

Development.—The general advance of exploration, colonization and civilization has moved eastward and northward, instead of westward as with us. From the older settlements of the Cape

1891. L. DE LAUNAY: Les mines d'or du Transvaal. Ann. des Mines, Serie 8 Tome XIX., p. 102.

1892. WALCOT GIBSON: Geology of Gold-bearing and Associated Rocks of the Southern Transvaal. Quar. Jour., XLVIII., pp. 404–437.

1894. G. A. F. MOLENGRAAF: Geologie der Umgegend der Gold-felder in Süd-Afrika. Neues Jahrb. f. Miner, etc., Beilage Bd. IX., p. 175.

1894. BERGRATH SCHMEISSER: Ueber Vorkommen und Gewinnung der nutzbaren Mineralien in den Süd-Afrikanischen Republik. D. Reimer, Berlin, 1894.

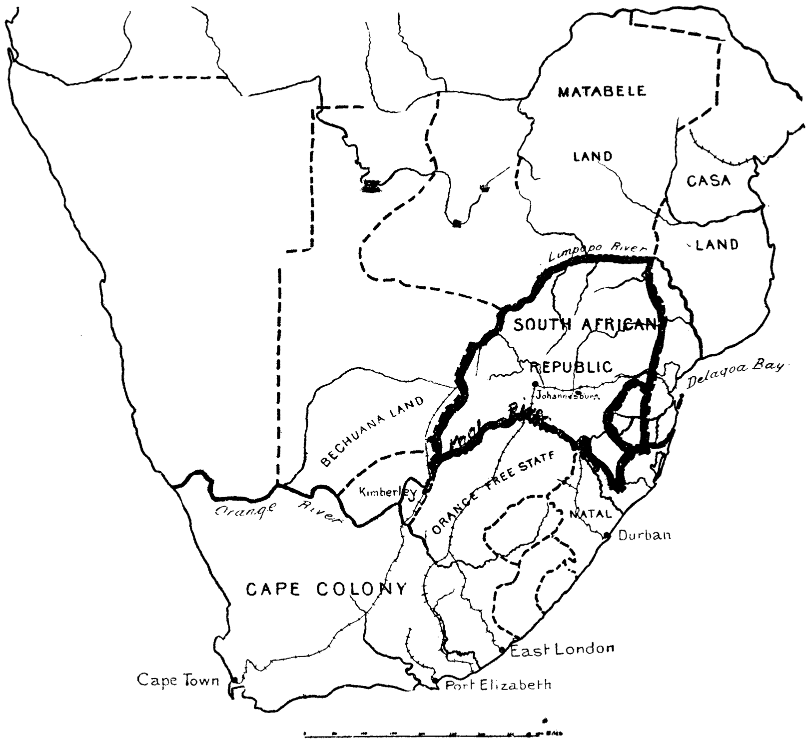
1894. A. PELIKAN: Goldführendes Conglomerat von Witwatersrand. K. K. Reichsanstalt, No. 16, December 18, 1894, p. 421.

1895. F. H. HATCH and J. A. CHALMERS: Gold Mines of the Rand. Macmillan & Co., New York and London, 1895.

Among geologists who have written in earlier times upon the geology of the southern portion of Africa, but not directly upon the South African republic, may be mentioned A. G. BAIN (Quar. Jour., 1845), R. N. RUBIDGE (Quar. Jour., 1854–6), ANDREW WYLEY (1857–8), G. W. STOW and C. L. GRIESBACH (Quar. Jour., 1870), E. J. DUNN, On Diamonds (Quar. Jour., 1874, 1877 and 1881), W. H. PENNING, On Coal (Quar. Jour., 1884), MOULLE (Ann. des Mines, 1885), E. COHEN (Neu. Jahrb., 1887).

The only geological map of South Africa is one made by E. J. Dunn, as Geologist of the Government of Cape Colony, and published in 1887. This covers most of the South African republic, but has no topographic base, and its geological outlines in the more northern portions are very sketchy.

Colony it spread eastward, then northward along the coast line, and later the search for useful minerals led people into the desolate interior. Coal was the first desideratum, and that was found in the beds of the first high plateau, or Karoo region. Further



NOTE.—The accompanying sketch map shows roughly the political divisions of the southern portion of the African Continent, the location of the principal mining towns and ports, and the main railroad lines.

advances into this region led to the discovery of the diamond deposits, and the foundation of the Orange Free State.

Following northwestward along the coast of the Indian Ocean, through Natal and Zululand, exploration next developed gold-bearing quartz veins in the valleys of the Crocodile River which debouches into Delagoa Bay, and of the Oliphant's and other tributaries of the Limpopo River which forms the semi-circular

northern boundary of the South African republic. This state is more commonly known as the Transvaal, because it lies beyond the Vaal River, the northern and main fork of the Orange River, which divides the South African republic from the Orange Free State.

These first discovered gold fields now comprise many districts, the most prominent of which are the Lydenburg on the north, and the De Kaap and Komati on the south of the Crocodile River. Furlonge describes this region in the following words: "A large plateau stretches from east to west across the Transvaal, which is called the 'High Veldt.' It is generally level or gently rolling, and has an average elevation of 6000 feet above the sea; it is destitute of timber, and in fact greatly resembles the western prairies of North America, and rock outcrops are not common. It terminates very abruptly to the east and northeast, the descent of 2000 to 3000 feet into the mountainous country that occupies its borders being made in a very short distance. These mountains extend in an easterly direction for a distance of forty miles, when they again terminate, very abruptly, in an apparently flat region composed of marshes and sandy plains, sloping gently but regularly to the shores of the Indian Ocean, a distance of about 100 miles."

It was the gold fever, resulting from the rich discoveries in the De Kaap district that started prospecting in the spring of 1886, and caused the unexpected discovery of gold in fair quantity and of great extent in the Witwatersrand (white water range) at the northern end of the great plateau of the Orange Free State and thirty miles south of Pretoria. Toward the end of the same year the township of Johannesburg, now a city of 30,000 inhabitants, was laid out and lots sold to the amount of £13,000. Shares were quoted on the Johannesburg exchange in June 1887, and by November of the same year sixty-eight companies, with a nominal capital of £3,000,000 had been formed. A boom soon set in, which lasted till the end of 1889, when it burst, and the reaction continued for several years, but the increasing output of gold and augmentation of dividends in 1892

and 1893 called the attention of outside capital to the mines again. In 1894 the Transvaal furnished one-fifth of the total gold product of the world, and was only exceeded among individual nations by the United States and Australia.

GEOLOGY.

The geological formations of South Africa are grouped by most geologists under the following four heads given in descending order: (1) recent deposits, (2) Karoo formation, (3) Cape formation, (4) Primary formation.

Recent deposits.—There is apparently no evidence of recent glacial action in South Africa. Dunn, in his early descriptions of the diamond deposits, attributed a glacial origin to certain bowlders observed near the Kimberley district, but afterwards withdrew this explanation of their origin as untenable. Furlonge says of the De Kaap region: "I have diligently searched for, but failed to find, evidences of glacial action, phenomena with which I happen to be very familiar from my residence in the Lake Superior district and the country north of it." Other geologists do not refer directly to the question, but all note the great extent of what they call laterite,[1] a formation which appears to result from the surface decomposition of rock-in-place, and to be similar to that found in the Appalachian region of the United States south of the limits of glaciation. This surface disintegration is so deep and so widespread that outcrops are few and prospecting is thereby rendered difficult. While placer gravels are infrequent and of limited extent, according to Schenck, gold is obtained by hydraulic washing of the laterite (or saprolite) of diabase beds and of surface flows covering the Cape formation in the Lydenburg district, north of the Crocodile River. Furlonge, in his description of the De Kaap region, remarks on the large areas of decomposed granite in flat places and natural

[1] G. F. Becker proposes the term saprolite (from σαπρός = rotten) for decomposed rock in place, objecting to the use of *laterite*, because in its original sense it had a lithological signification, and applies in part to transported material. Gold-fields of the Appalachians, p. 43. Sixteenth Ann. Report Director U. S. Geol. Survey, Wash., 1895.

drainage channels, whose decay he ascribes to the agency of meteoric waters remaining long in contact with the rock. The area on which the town of Barberton is situated is sixteen by eighteen miles in extent. Throughout these areas are what are called "Tongas," that is water-washes, with intricate drainage channels and perpendicular walls, not unlike the Bad-land topography of the West. The depth of this decomposition may reach 200 feet, while on the steep slopes of adjoining hills, and in bowlders rolled down onto the surface, the granite is hard and undecomposed. The same decay is found in other feldspathic rocks.

Primary formation.—Under this head are included granites, and a series of schists called by Schenck the Swasi-schists, because of their abundance in Swasiland to the south and east of the De Kaap basin.

The granite is described by Molengraaf as consisting of microcline granite and of tonalite (plagioclase granite), muscovite being developed in the former as an alteration product of feldspar. Furlonge remarks on its light color and the absence of dark minerals in the De Kaap district. I find no explicit statement of the relative age of granite and schists, but Molengraaf says the schists rest upon the granite, and Schmeisser describes them as dipping away from it in three directions. For the most part these schists appear to be compressed into close folds and stand at steep angles, but in some cases they occupy a nearly horizontal position. While classed under a single head, it does not appear impossible that they may belong to two distinct series of rocks. According to Molengraaf they consist mostly of quartz-sericite and actinolite schists, and in places of conglomerates and sandstones, also carrying sericite. Schmeisser describes them as in part metamorphosed beds of sedimentary origin, such as slates, quartzites and magnetite-quartz (calico) rock, but to a much greater extent of metamorphosed schists with greenstone dikes and sheets, the latter altered into hornblendic, chloritic and serpentinous schists. Molengraaf speaks of quartz-porphyry dikes in the schists around the granite. Schmeisser says gold-bearing veins occur wherever the Swasi formation is developed. They

occur also to a considerable extent in the granite. Schenck considers that the quartz veins are intimately connected in most cases with interbedded sheets of greenstone, sometimes altered into schists, and that the greenstone "appears to be the mother-rock proper of the gold." They appear to resemble the gold veins of the Appalachians in that they are mostly parallel in dip and strike with the stratification (foliation?) planes, or cross them at a slight angle, and are nevertheless true fractures and often contain fragments of the country rock. Furlonge speaks of quartzite-like bands, which, resisting erosion, stand out on the surface in ridges and are called "bars." He considers them to be the result of silicic replacement, and says the principal gold deposits are found in or near these bars, but always in the proximity of some eruptive rock. Often instead of gold they carry deposits of iron oxide of great extent. The gangue of the veins is quartz, and, besides gold, much iron pyrites, some sulphides of copper, antimony, arsenic, lead and zinc occur.

The rocks of this formation stretch northward over 80 kilometers from the steep descent of the Drakensberg, along the eastern border of the high plateau, forming the Murchison range, and constitute the country rock of the De Kaap, Komati, Selati, Little Letaba and Smitsdorp districts. They also occur between Pretoria and Johannesburg. They are considered to be of Silurian age, partly from indistinct fossils remains, but more from stratigraphic correlation with beds underlying uncomformably the Cape sandstones in the Cape Colony, which have been determined to correspond most nearly to the European Silurian.

The Cape formation, so-called because supposed to correspond in age with the Cape sandstones of the Cape Colony, overlies uncomformably the Swasi-schists, and is in turn unconformably overlaid by the beds of the Karoo formation. It contains the gold-bearing conglomerates. Its beds are sometimes upturned, even quite steeply, but are not contorted, compressed or dynamo-metamorphosed to such an extent as are the Swasi-schists. No fossils have yet been found in its beds, but from its relative position, it is supposed to be either Devonian or Lower Carboniferous.

As the most important formation, its description will be given last.

Karoo formation.—Under this head are included a great series of beds, generally occupying a nearly horizontal position, which form the great central plateau or High Veldt of the Orange Free State, and extend into Natal on the east and Cape Colony on the south, leaving a comparatively narrow belt of upturned older rocks between their bluffs and the ocean. Its several subdivisions are variously named and classified in different places and by different writers. Those most commonly adopted are in descending order:

Stormberg beds,	Volcanic. Cave sandstones. Red beds. Molteno beds.
Beaufort beds,	Karoo beds. Kimberly beds.
Ecca beds,	Ecca beds. Dwyka conglomerate.

The beds of the Karoo formation consist mainly of argillaceous, siliceous, and marly slates and sandstones, with a few limestones; they are generally much softer than corresponding rocks of the Cape formation, and often of variegated colors; the coal-bearing rocks are generally coarse-grained, light-colored sandstones. The two lower of the above general divisions contain a Glossopteris flora (of the fern family) and are hence supposed to be as old as Triassic, and possibly Permian or upper Carboniferous in part. According to Hatch the coal seams are confined to the Molteno beds of the upper division, but Schmeisser, from the finding of Glossopteris remains, considers that some of the coal beds belong to the earlier rocks. The formation is traversed by dikes and sheets of greenstone and other eruptive rocks, especially the middle division.

It is in volcanic necks cutting the Kimberley shales that the diamonds occur, and, as early as 1881, Dunn suggested that they

were formed from the carbon in the shale through the agency of the intruded eruptive rocks.

Near the Witwatersrand the coal-bearing beds transgress horizontally over the upturned edges of the auriferous conglomerates, and coal mines are worked at Bocksburg, Brakspan, Olifants River and other points within 12 to 20 miles of Johannesburg. The coals are gas, coking, blacksmith and steam coals, all varieties being sometimes found in a single district. Beds up to 20 feet in thickness occur. Dunn speaks of an anthracite vein intersecting the Karoo beds vertically at Buffel's Kloof in Cambedoo. Semi-anthracites are found, according to Schmeisser, in Bocksburg and Brakspan, which have a high percentage of ash. The ash from that of the former place, tested by Professor Stelzner, yielded to the assay $4.50 per ton in gold.

Remains of Labyrinthodonts (amphibia), and Dicynodont (few-toothed) and Oudenodont (toothless) reptiles from these beds have been described by Owen and Huxley. Both Equisetæ and Glossopteris occur in the lower Karoo beds, according to Dunn. This peculiar fauna, and more particularly the Glossopteris flora, which apparently was only developed in the southern hemisphere, has called the attention of palæontologists especially to these beds. Schenck says that the fossil flora of South Africa, especially the characteristic *Thinnfeldia odontopteroides*, stands in connection with that of the Argentine republic in South America, with the Radschmahal beds of India, the Hawkesbury and others of Australia, and those in the Jerusalem basin of Tasmania.

In most of these regions the base of the coal-bearing beds, in which this peculiar flora has so suddenly replaced that which in other countries characterizes the Carboniferous formation, consists of a conglomerate carrying peculiarly large, angular rock fragments. These features have seemed to many geologists to indicate the former presence of a southern ice-sheet. On Dunn's geological map the Dwyka conglomerate, which constitutes the lowest member of the Karoo formation, is called "glacial conglomerate." Some earlier geologists, seeing it probably at different exposures, have called it claystone porphyry, others trap-conglomerate.

A. H. Green, who visited South Africa in 1882 for the purpose of examining the coal-bearing formations, speaks of it as a great mass of breccia and conglomerate, in which the fragments are largely granite with some quartzite of varying character and very coarse-grained in places. He considers the volcanic origin that had been suggested for it by no means certain, and remarks that the size and regularity of the pebbles suggest the action of ice and that some of the pebbles observed by him had scratches resembling glacial scratches. On weighing the evidence, however, he concludes that it was a coarse shingle formed along a receding shore line.

He considers that there is a great unconformity between the Ecca beds and the overlying Kimberley shales, which he observed at one point overlapping the upturned edges of the former; he thought to recognize a basement conglomerate at the bottom of the Kimberley shales, which might have been confounded with the Dwyka conglomerate. He is inclined to regard the Karoo formation above the Ecca beds as of fresh water origin. Others have regarded the fossil evidence as in favor of a lacustrine origin for the whole series.

Cape formation.—The beds included under this head are intermediate in lithological character and in degree of deformation, as well as in stratigraphical position, between the Swasi-schists and the Karoo formation. They consist of sandstones, conglomerates and shales, and in some regions of dolomitic limestones. As yet they have proved entirely barren of fossils. They extend over the southern, middle and western parts of the Transvaal. According to Hatch the long range of the Drakensberg consists of these beds, and thus they probably extend to the Cape Colony where they are represented by the Table mountain sandstones and the shales, sandstones and quartzites of the Bokkeveldt beds. The age of the latter by fossil evidence most nearly corresponds to the European Devonian or Lower Carboniferous.

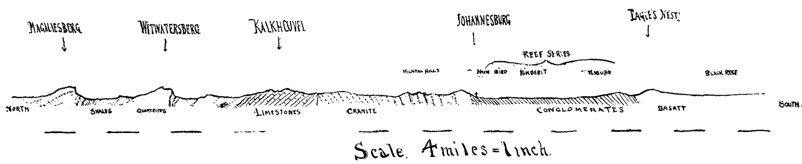
Within this formation name are comprised several series of rocks of very great aggregate thickness, with regard to whose

relations to each other there is some difference of opinion among geologists. They may be separated into three groups.

1. *The Quartzite and Shale group* of Gibson (*Magaliesberg beds* of Penning) underlying the auriferous conglomerates north of Johannesburg, and considered by Gibson to belong to the same series, though separated by a fault, which Molengraaf holds to be an unconformity.

2. The great series of *auriferous conglomerates.*

3. A series of *blue dolomites,* alternating with siliceous or cherty beds. Those which occur in the Malmani district, to the west of Johannesburg, Molengraaf considers to be the upper



Section across Rand.

part of the Cape formation, while immediately north of Johannesburg similar dolomites underlie a series of quartzite and shales, which Schenck considers to correspond to those directly beneath the auriferous conglomerates. These dolomites have a wide distribution in the Western Transvaal and extend into Bechuana land.

The general relations of these beds is shown in a section given by Hatch, which is apparently drawn to scale, and extends from the Magaliesberg on the north, through Johannesburg, to the Black reef beds on the south, a length of over twenty miles. On the line of this section immediately to the north of Johannesburg, are the quartzites and shales, the former standing out as east and west ridges between shale valleys. They have a steep dip to the south, and are succeeded to the north by granite and schists, supposed to correspond to the Swasi-schists. To the north of the granite, and dipping northward away from it, are the dolomitic limestones of the Kalkheuvel range; beyond these again, still dipping north, is a series of quartzites and shales

forming the Witwatersberg and Magaliesberg ranges, which are supposed to correspond with these on the south side of the anticline, though not altogether similar lithologically. If, as Molengraaf maintains, the limestones are the Malmani dolomites, and belong above the conglomerates, the latter must be faulted down on the north side of the granite, and not appear at all at the surface.

Returning again to Johannesburg and following the section line southward, there appear, resting on the quartzites and shales and apparently conformable with them (Gibson thinks they are only separated by a fault, but Molengraaf thinks there is an unconformity) a thick series of reddish sandstones with some shale, which enclose gold-bearing conglomerate beds of varying thickness, and form a flat, rolling country sloping gently south. These dip steeply at the outcrop but shallow in dip to the southward, and in a few miles are capped by a body of eruptive rocks, called by Hatch, in one place, "a hard, fine-grained greenstone or melaphyr" and in another "an overflow of igneous rock of basaltic composition, known as the Klipriversberg amygdaloid." Molengraaf speaks of it as an overflow of diabase and melaphyr amygdaloid with porphyrite, varying in thickness from 400 meters south of Johannesburg to 900 meters near Klerksdorp. This forms the hills called the Eagle's Nest.

Upon the amygdaloid rests a series of shales, quartzitic sandstones, and gold-bearing conglomerates which he calls the Boschrand (wooded mountains), but which are more commonly known as the Black reef series, because of a black seam which forms its footwall. This series Molengraaf considers younger than the lower sediments and than the igneous rocks, but Gibson considers the intrusion of the igneous rocks to have been the latest phase. Hatch, to prove that they were deposited unconformably on the older conglomerates, adduces the facts (1) that they are nearly flat (10° against 45° to 80° dip of the lower beds), (2) that followed eastward they overlap the older series, (3) that they occasionally contain rolled fragments of the older conglomerates. The total thickness of this southerly dipping

series of sandstones and conglomerates, neglecting possible reduplication by faulting, is given as 17,000 to 18,000 feet. Schmeisser enumerates in this series some seventy beds of conglomerates, of which by no means all contain gold, and of those that do, comparatively few have enough to pay for working, or are *payable*, as the South African phrase is. They are generally divided into groups or series of reefs, of which Hatch gives four in descending order beneath the Black reef series, viz., the Elsburg series : the Kimberley series : the Livingstone and Bird series : the Main reef series. The latter is that upon which the principal mines are working today. Beneath the Main reef series is the Dupreez or Rietfontein series, two and one-half miles north of Johannesburg, which has only been traced 10,000 feet along its strike, whereas the Main reef series has been traced more or less continuously for forty-five miles on the strike. Across the strike from the Dupreez outcrops to those of the Black reef series, is eight to ten miles.

As shown by the underground workings these gold-bearing beds are traversed by dikes and sheets of greenstone and considerably faulted.

Twenty-five miles south of Johannesburg, in the Heidelberg region, they are working on a series of a similar conglomerates, which dip 30° to the northward, and are assumed to belong to the south side of a syncline. It has not been possible, however, to correlate the Heidelberg and neighboring Nigel series with those outcropping in the Johannesburg region. Going eastward, on the strike both these and the southerly dipping beds pass within a few miles under the horizontal coal beds of the Karoo formation. The Johannesburg series have been proved under these beds by borings, and are assumed to curve round to the southwestward and find their continuation in the Nigel and Heidelberg fields. To the westward again the Johannesburg beds, at a distance of fifteen to twenty miles from the city, bend to the southwest, toward Potchefstrom and Klerksdorp where similar conglomerates outcrop. The outcrops thus form a sort of horseshoe curve. It is naturally a matter of great importance

to determine accurately the structure of the middle of this basin, where the surface is marshy or shows only outcrops of igneous rocks, and upon this subject much has been written.

Near Johannesburg the dip of the beds is generally 45° to 80° at the outcrop, though in a few instances not over 25°. This inclination decreases with depth, quite rapidly though with no uniformity, and at vertical depths of 500 to 1000 feet, it has usually become 30° or less; the borings show a probable angle as low as 12° at greater depths. Should this decrease continue with sufficient rapidity, the whole basin, even at its deepest part, might be within the limits of profitable mining. Gibson, who is inclined to extreme views in regard to structure indications, says that the surface of the foot and hanging walls of the "reefs" or "bankets" are smooth and polished; the pebbles flattened, and sometimes completely shattered; the cementing material decidedly schist-like and squeezed in and out around the pebbles. He remarks further that the conglomerate beds are generally found to decrease in number as greater depth is reached. All these facts he regards as evidence of strong compressive movement combind with overthrust faulting. The apparent rapid decrease of angle of dip in depth he seems to think due to repetition by reversed faulting and he hence opposes the theory of a simple basin structure. The igneous rocks he regards as much later than the conglomerates, and probably later than the movement of compression, since the diorite intrusions show no effects of it.

Molengraaf, on the other hand, does not consider that there is any considerable folding in these beds, and thinks Gibson's proof of overthrust faulting weak. He admits that both strike and dip faults are common, and that there are evidences of movements within the beds; he considers that these result from thrust faults with movement from north to south instead of from south to north as Gibson maintains. The rapid shallowing of the dip he thinks easily explained if the steep upturning of the beds around the rim of the basin is considered due to dragging of the strata over each other.

The facts presented by Hatch, who devotes much less consideration to geological than to economic questions, lead one to conclude that there is one large and several smaller synclinal basins, none of which can be fully traced on the surface, and which are undoubtedly much broken by dynamic movements which have been accompanied by the intrusion of igneous rocks, mostly on the fault planes, but to a certain extent as intrusive sheets and laccolites. It seems not unlikely that the apparent basin structure indicated by outcrops, will be found to be much broken in depth by these igneous intrusions.

The auriferous conglomerates of the Rand.—The area within which is the principal development of auriferous conglomerates is estimated at 2000 square miles. Gold deposits occur also in other beds assumed to belong to the Cape formation, notably in the dolomites of the Malmani district, as vertical quartz veins, and in the sandstones of the Lydenburg district, which rest on dolomites. None of these have yet assumed any considerable economic importance, however, and it is the area called for short the "Rand" that produces over nine-tenths of the South African gold.

In this area, though gold is found in most all of the several reef series enumerated above, it is rarely in paying quantities outside of the Main reef series, upon which most of the mines near Johannesburg are working. In this series are several beds of conglomerate known respectively as the north, main, middle, and south reefs, and main and south reef leaders (this name is given to thin beds of conglomerate) not more than two or three of which are usually productive in the same mine. Schmeisser says the tenor in gold varies inversely with the thickness of the beds, and in many mines the principal values are obtained from the main reef leader, which averages only 15 inches in thickness while some of the reefs average six feet. Although there is considerable variation in the richness of the different beds, and of the same beds from one point to another, yet taking the district as a whole the gold seems to be distributed with remarkable uniformity, as compared with other mining districts. Schmeisser

estimates $15.00 per ton as the average tenor of the ore mined throughout the whole district. Hatch puts it at $10.00, or half an ounce.

The central district of the Rand, on the Johannesburg side of the basin where the greatest concentration of mines exists at present, is 11½ miles long. The workings of these mines extend now to a depth of 800–900 feet in the case of those which started from the outcrop, while deep-level mines, or those which do not own the outcrop, are down as far as 2000 feet, in each case reckoned on the dip. Drill holes sunk at various points in this extent, to vertical depths of between 2000 and 3000 feet, have proved the gold bearing conglomerates to distances of up to 8000 feet from the outcrop, and found, for the points thus tested, about the same average tenor in gold as higher up, with similar variations from point to point.

The conglomerate beds and the sandstone which enclose them have a reddish tinge near the surface which is due to the oxidation of the finely divided iron, but in depth have the greenish or bluish-gray color common to rocks containing sulphides of iron. The conglomerate beds vary in thickness from a few inches up to six or more feet, and the pebbles of which they are composed from the size of a pea to that of a hen's egg or even larger. These pebbles are generally smooth and well rounded, sometimes flattened and not infrequently cracked and fissured; angular pebbles are also found. They are mostly composed of white or smoky quartz; quartzite is also mentioned as a constituent. Gibson speaks of pebbles of a yellowish talcose material, like hardened clay, which may be altered igneous rocks. The cement consists mostly of small quartz fragments, and abundant but irregularly distributed pyrite grains. Under the microscope it is seen to contain, beside quartz and gold, pyrite, magnetite, zircon. rutile, muscovite and chlorite, the last two minerals and some of the quartz being of secondary origin. The gold, which occurs almost exclusively in the cement, is generally invisible to the naked eye. When it does occur in the pebbles it is found in the delicate cracks or fissures associated with quartz which appears

to be secondary. Gold is sometimes found also in the sandstones between the reefs.

Numerous dikes and some intrusive sheets traverse the beds; the intrusive rocks are generally basic; diabase, olivine and bronzite-diabase, gabbro and olivine-norite being among the varieties recognized. The dikes generally follow fault planes. The faults, which are quite frequent, are both dip, strike and reversed faults. Quartz veins are said to cross the gold-bearing beds, and at the intersection the quartz becomes quite rich.

Origin of the gold.— From the very earliest discovery of these deposits the question as to how the gold came to be distributed in such quantities over such great areas and in so many different beds has been one that has occupied the attention of all geologists who have visited the region. Probably the largest number, certainly among the earlier observers, have considered that the gold, like the pebbles of which the beds consist, results from the degradation and concentration by sea waves of material from an ancient landmass of Swasi-schists. They have seen in the quartz of the pebbles a resemblance to that of the veins which are so abundant in these rocks in the De Kaap and other outlying districts. A few have held that the gold was chemically deposited from the waters of the ocean; and another, and in late years an increasing, number believe that it has been deposited from ascending or descending thermal solutions.

Schmeisser brought back specimens of the conglomerate ore from six of the principal mines of the Rand, which were submitted to Dr. Koch for microscopical examination. The main results of this examination are as follows:

The pyrite shows the effects of wear in rounded edges, etc., and also occurs within the quartz pebbles; hence it is undoubtedly of primary origin. The same is true of the magnetite and zircon. The rutile is, however, not original, and the muscovite and chlorite are evidently formed from the alteration of other minerals. Secondary quartz occurs both in the matrix and filling the cracks in the pebbles that result from dynamic action; it contains fewer inclusions than the primary quartz. The gold con-

tained in the specimens (eight in number) that he examined is of secondary formation and not placer gold, for the following reasons:

1. It occurs either in microscopic crystals or in aggregates of angular form. Rounded and polished grains are altogether wanting.

2. It is not observed as inclusions in the quartz pebbles, but is confined to shattered zones and fissures filled with secondary quartz.

3. In the matrix, the gold is aggregated with pyrite grains, for the most part forming deposits on the outside of them, filling cracks and bays in them, and sometimes nearly enclosing them. It is noticeable, moreover, that the gold is connected only with grains of pyrite that have been separated from their matrix. The pyrite that is still enclosed in quartz pebbles is free from gold.

In conclusion he says: "Whether the above observations on the occurrence of native gold can be considered of universal application, or whether they only fit local phenomena must remain undecided for the present and can only be finally determined by the investigation of more extensive and complete material than was submitted to me."

Pelikan, on the other hand, from the examination of five specimens from, in part, the same mines, brought back to Vienna by Professor Suess, comes to a different conclusion with regard to the origin of the gold, though confirming the correctness of Koch's observations in every other respect. His reasons are not so clearly or definitely stated as those of Koch, but seem to be mainly the following:

1. The nature of the pebbles indicates that they came from quartz veins; they have the same colors as are described for the vein quartz of the Swasi-schists.

2. The form of the gold—in grains (Körner) and in flakes (Flittern)—as well as its distribution in the rock, indicates its foreign origin.

3. As regards the critical question whether gold occurs in the

pebbles, he says that after searching a great number of thin sections he has found moss-gold in one or two; and moreover that after grinding up the rock and treating it with *aqua regia* to dissolve the free gold, the quartz fragments often showed included gold that had not been removed. He says, moreover, that Schmeisser answers this question in the affirmative.

This is not, however, a fair statement of the latter's opinion, which in his own words is as follows: "The gold occurs almost entirely in the cément or matrix, in rare cases also in the pebbles. In the latter cases, however, it appears to be found only in the minute cracks that traverse the quartz." Koch, from whose observations he formed his opinion, considers, as shown above, the gold in such cracks to be the secondary, as well as the quartz which encloses it. His (Schmeisser's) final words with regard to whether the gold was deposited with the conglomerate as "fossil placer deposits," or was brought in subsequently in solution, are: "The observed phenomena bear evidence in part for the one, in part for the other solution."

Hatch, while declining to discuss the various hypotheses that have been brought forward, says, that the quartz pebbles are derived from veins in the Primary formation, but they are not the source of the gold because it does not occur in them (the pebbles); that the movements produced faulting; that the dikes followed the fault fissures; and that the same planes acted as channels for the introduction of ascending mineralizing solutions. He says that no evidence has been found in favor of the locally prevalent theory that the dikes have acted beneficially, as regards gold contents, on reefs in their immediate neighborhood.

The Future of the Rand.—So much attention has evidently been given to the question of the origin of the gold not only because of its intrinsic interest, but because it has an important bearing upon the future productiveness of the region.

The grounds on which auriferous conglomerates outcrop have, it may be assumed, been all taken up or "pegged out," as the South African phrase is; and already many so-called deep

level mines have been opened; *i. e.*, those whose surface lines do not include the outcrop, but which like the Tamarack and other conglomerate mines at Lake Superior, first reach the payable beds at considerable depths. How far from the outcrop toward the middle of the basin it may be profitable to open deep level mines, depends upon three factors:

1. The angle at which the beds descend, or the depth at which they will be found under a given point on the surface.

2. The vertical depth at which the difficulties of mining will neutralize the profit.

3. The extent in depth, or the distance from the outcrop to which the conglomerate beds will continue to be payable.

If the gold is entirely placer gold, that is if it has all been brought into the beds mechanically, by the action of sea waves —there has been no suggestion of old river channels—it is evident that there must be a limit to the distance from the shore to which so heavy a metal could have been transported.

That wave action may concentrate the gold in beach gravels sufficiently to constitute workable placers, has been proved on the coasts of California, Oregon and Alaska, though practically such placers have not yielded much profit to those working them, because the pay streaks are constantly shifted by storms and ocean currents.

The best authenticated instance of a fossil placer on an old shore line (not a river bed) known to the writer, is the conglomerate at the base of the Potsdam sandstone, near Deadwood in the Black Hills. According to W. B. Devereux,[1] who has given the best description of these deposits, the conglomerate which is rich enough to be profitably mined occupies a narrow belt, not over one and one-half miles wide, in the immediate vicinity of the Great Homeslates group of deposits in the underlying crystalline schists, from the degradation of which it is evidently derived. The gold in the Potsdam quartzite of Bald Mountain and other districts of the Black Hills, however, is found, not in rounded pellets and flattened flakes, but finely divided and, when visible, is in the

[1] Trans. Amer. Inst. Mg. Engrs., Vol. XVII., p. 572.

brown powdery form that comes from precipitation. This he considers to have been chemically deposited as a result or sequence of the intrusion of igneous rocks in sheets or dikes, and more or less contemporaneously with the ores of silver that occur in these rocks.

That gold may be carried to a considerable distance from the shore in the waters of a sea or lake, is proved by deposits recently examined by the writer near Denver, Col., where payable placers occur, at fifteen miles or more from the ancient shore line of the lake, in Tertiary beds made up of detritus of granitic rocks that form the nucleus of the Colorado range. In this case, however, the gravels that contain enough gold to be worked result from the rearrangement and concentration of the Tertiary lake beds in an ancient stream bed, the gold in the undisturbed Tertiary beds being too small in amount to be of economic value.

Explorations within the conglomerate beds of the central district of the Rand have, as already shown, extended about one and one-half miles from the outcrop (which may be somewhere near the ancient shore line) and are still within the payable limit, but this does not prove that at several times that distance the payable limit may not have been passed. The fact, mentioned by Schmeisser, that the beds are generally richest at the bottom where the gravel is coarsest is, in so far, an evidence in favor of the placer theory. On the other hand many facts presented above seem incompatible with this theory, so that it would seem probable that while the beds contain gold that has been introduced mechanically, they also contain some that has been added chemically since the formation of the beds by concentration, either from adjoining sedimentary or from igneous bodies along areas that have been rendered accessible by dynamic movements.

As to the other two factors, it seems abundantly proved that the steep dips at the outcrop do not continue in depth, but at what depth the auriferous conglomerates will be found in the middle of the basin can only be finally determined by actual exploration with the drill.

The practical limits in depth at which mining can be profit-

ably carried on, have been recently extended by the experience of the Lake Superior mines, where the new shaft at the Calumet and Hecla mine is down below 4700 feet and destined to go to 5000. In this case, however, conditions are unusually favorable, for the increment of temperature with depth is, according to a recent statement of A. Agassiz,[1] only 1° in 223 feet, or 79° at the bottom of the present shaft. In South Africa the increment as determined by Hamilton Smith is 1° in every 82 feet, which would produce a temperature of 100° at 3000 feet. This increment, though below the average, is, there is reason to believe, somewhat overestimated; more recent estimates make it less than 1° for every 100 feet, which would give only 108° (F) at 4000 feet.

Production, Past and Future.—In conclusion it may be of interest to consider some of the figures showing the gold production of this remarkable region.

Its output for 1894 was gold to the value of £7,800,000 and for 1895 it is estimated to reach nearly £8,750,000. Hatch estimates that by 1900 the annual output will be over £20,000,000. Up to July 1895 it had already produced £26,670,539. Estimates of the available supply of gold in the central district of the Rand with its eleven and one-half miles of outcrop are given as follows:

By Hamilton Smith - - - - - -	£325,000,000
" Bergrath Schmeisser - - - - -	346,000,000
" F. H. Hatch - - - - - -	382,000,000

As these estimates have been arrived at independently and by somewhat different methods, Hatch allowing a greater depth for profitable working than the others, their slight difference is rather remarkable. Hatch further estimates a probable product for the whole region, including outlying districts, of £700,000,000, of which £200,000,000 will be profit. This amount is greater than the product of the whole United States up to date.

S. F. EMMONS.

[1] Am. Jour. Sci., Vol. L, Dec. 1895, p. 503.